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Encyclopedia of Laser Physics and Technology

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Q-switched Lasers

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Definition: lasers which emit optical pulses, relying on the method of Q switching

A Q-switched laser is a laser to which the technique of active or passive Q switching is applied, so that it emits energetic pulses. Typical applications of such lasers are material processing (e.g. cutting, drilling, laser marking), pumping nonlinear frequency conversion devices, range finding, and remote sensing. Note that the article on Q switching contains more details on Q-switching techniques.

Q-switched lasers can be pumped either continuously or with pulses, e.g. from discharge lamps (particularly for low pulse repetition rates). For continuous pumping, the gain medium should have a long upper-state lifetime to reach a high enough stored energy rather than losing the energy as fluorescence. In any case, the saturation energy should not be too low, because this could lead to excessive gain, so that the premature onset of lasing is more difficult to suppress. The latter problem can occur particularly for fiber lasers.

Types of Q-switched Lasers

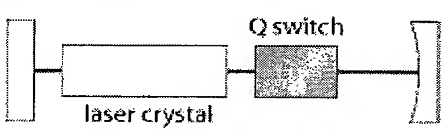

Figure 1: Schematic setup of an actively Q-switched laser.

The most common type is the actively Q-switched solid-state bulk laser. Solid-state gain media have a good energy storage capability, and

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bulk lasers allow for large mode areas (thus for higher pulse energies and peak powers) and shorter laser resonators (e.g. compared with fiber lasers). The laser resonator contains an active Q switch – an optical modulator, which in most cases is an acousto-optic modulator.

For wavelengths in the 1-μm spectral region, the most common pulsed lasers are based on a neodymium-doped laser crystal such as Nd:YAG, Nd:YVO_4, or Nd:YLF, although ytterbium-doped gain media can also be used. A small actively Q-switched solid-state laser may emit 100 mW of average power in 10-ns pulses with a 1-kHz repetition rate and 100 μJ pulse energy. The peak power is then ~9 kW. The highest pulse energies and shortest pulse durations are achieved for low pulse repetition rates (below the inverse upper-state lifetime), at the expense of somewhat reduced average output power. A somewhat larger Nd:YAG laser with a 10-W pump source (e.g. a diode bar) can reach pulse energies of several millijoules. Nd:YVO_4 is attractive particularly for short pulse durations and high pulse repetition rates, or for operation with low pump power.

Q-switched lasers with longer emission wavelengths are often based on erbium-doped gain media such as Er:YAG for 1.65 or 2.94 μm, or thulium-doped crystals for ~2 μm.

Significantly larger pulse energies can be obtained from amplifier systems (MOPAs). For high average powers combined with moderate pulse energies, fiber MOPAs, also called MOFAs, can be used.

Particularly for low pulse repetition rates, lamp pumping can be an economically favorable option, since discharge lamps are much cheaper than laser diodes for a given peak power. For higher powers, however, diode pumping becomes more attractive, also because thermal effects in the laser crystal are strongly reduced.

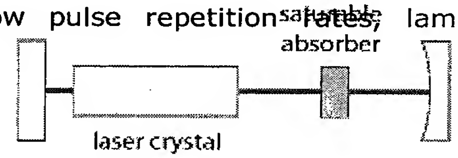

Figure 2: Schematic setup of a passively Q-switched laser. The saturable absorber is a crystal (e.g. of Cr:YAG) within the laser resonator.

A *passively* Q-switched laser contains a saturable absorber (passive Q switch) instead of the modulator. For continuous pumping, a regular pulse train is obtained, where the timing of the pulses usually cannot be precisely controlled with external means, and the pulse repetition rate increases with increasing pump power. The most frequently used saturable absorbers for 1-μm lasers are Cr:YAG crystals.

Passively Q-switched microchip lasers have particularly compact setups. Such lasers typically emit pulses with energies between nanojoules and a few microjoules, average output powers of some tens of milliwatts, and repetition rates between a few kilohertz and a few MHz.

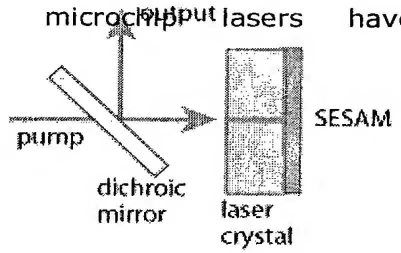

Figure 3: Microchip laser, passively Q-switched with a SESAM. The left-hand side of the laser crystal has a dielectric coating, serving as the output coupling mirror.

Particularly some of the smaller Q-switched lasers, but also some lasers with longer resonators containing an optical filter such as a volume Bragg grating, operate on a single axial resonator mode. This leads to a clean temporal shape and to a small optical bandwidth, often limited by the pulse duration. Other lasers oscillate on multiple resonator modes, which leads to mode beating effects: the optical power is modulated with frequencies which are integer multiples of the resonator round-trip frequency.

Fiber lasers can also be actively or passively Q-switched. However, all-fiber devices are fairly limited in terms of performance, whereas Q-switched fiber lasers containing bulk-optical elements (e.g. an acousto-optic Q switch, see Figure 4) are less robust and still less powerful than bulk lasers. The relatively small mode areas (even when using large mode area fibers) introduce problems with fiber nonlinearities and damage, which set limits on the pulse energies and particularly the peak powers achievable. Note also that the typically very high laser gain in a fiber laser has important effects on the laser dynamics; in particular, it can lead to the formation of a complicated temporal sub-structure.

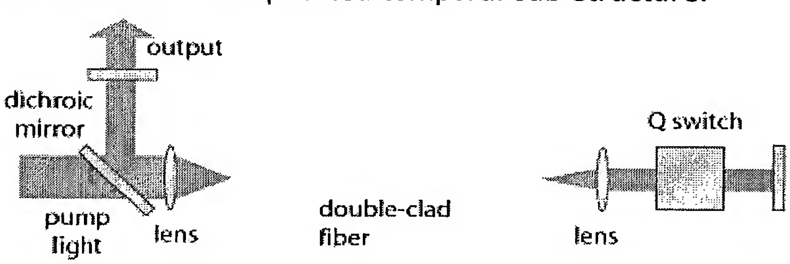

Figure 4: Setup of an actively Q-switched fiber laser.

On the other hand, high-power fiber amplifiers are suitable for amplifying pulse trains with high average power but moderate pulse energy. Some degree of nonlinear pulse distortion in such an amplifier is often acceptable for applications.

Design Issues

Depending on the design goals for a Q-switched laser, different solutions can be appropriate. In the following, some possible goals, encountered issues and tradeoffs are listed:

- For short pulse durations, a short laser resonator and high laser gain are required. The shortest pulses are achieved with microchip lasers (see above), because these can have extremely short resonators, but the pulse energies achievable are moderate. Short pulse durations (a few nanoseconds) combined with millijoule pulse energies are possible with compact solid-state lasers, particularly with end-pumped versions due to their higher gain. Thin-disk lasers allow for very high pulse energies, but are not suitable for very short pulses owing to their relatively small gain.
- High pulse energies require good energy storage. For continuous pumping, this means that a long upper-state lifetime is desirable. This results in advantages for ytterbium-doped gain media, e.g. Yb:YAG as compared with Nd:YAG, although these typically have lower gain and therefore generate longer pulses.
- A too high gain should actually be avoided, since it brings with it the risk of losing energy via ASE or parasitic lasing.
- The pulse repetition rate can often be varied in a large range, but this influences not only the pulse energy achievable, but also the pulse duration.
- At high optical intensities, the *damage* of intracavity components such as laser mirrors can be a problem. One therefore requires resonator designs with sufficiently large mode areas not only in the laser crystal but also on all resonator mirrors and in the Q-switch. Particularly in combination with a short resonator length, this can be difficult to achieve. Numerical optimization of resonator designs can sometimes lead to significantly improved performance values, together with improved stability, ease of alignment, and a long lifetime.
- A reduced emission linewidth can be achieved with injection seeding.

Laser Safety

Note that the high pulse energies and peak powers can raise serious laser safety issues even for lasers with low average output power. A single shot into an eye will in many cases be the last thing that an eye has seen. Such risks can be substantially reduced by using Q-switched lasers operating at eye-safe wavelengths.

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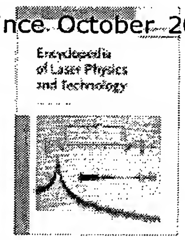
See also: Q switching, Q switches, lasers, nanosecond lasers, lamp-pumped lasers, laser safety, Spotlight article 2006-09-16, Spotlight article 2009-03-07

Categories: lasers, pulses

This encyclopedia is authored by **Dr. Rüdiger Paschotta**, the founder and executive of **RP Photonics Consulting GmbH**. **Contact** this distinguished expert in laser technology, nonlinear optics and fiber optics, and find out how his **technical consulting services** (e.g. product designs, problem solving, independent evaluations, or staff training) could become very valuable for your business!



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